

surfaces. All the layers were perfectly bonded together so there were no contact surfaces defined. The layers were modeled as a linear elastic material with an elastic modulus of 1.637 GPa, and a Poisson's ratio of 0.10. The Poisson ratio was lowered from the typical value of 0.40 because it seems to have an amplifying effect on the variation in stresses. Since  
5 buffer tubes are typically hollow and gel filled, the Poisson ratio is different than that of solid polypropylene material.

The analysis for the concentric layer model starts with an initial tensile stress applied to the first layer, for which an equilibrium solution is then computed. The remaining layers are not considered in the solution for this step. At the next step, the first layer will have some  
10 stress state, and the second layer will be activated with the initial stress value. The equilibrium solution will then be computed for both layers. At the end of the first step, the nodes common to the first and second layer may have moved, but the second layer will be activated strain free in the second step. The deformations are small, so the shape of the elements did not change significantly. The analysis was continued until all layers have been  
15 activated, and a final equilibrium state is determined.

The analysis was performed with an initial stress value of 10.0 MPa, to simulate a winding tension of 30.0 N. Figure 19B shows the circumferential and radial stress distributions at the final state. The stress values shown need to be multiplied by 1000 to obtain units of Pascals. The radial stress plot indicates zero stress at the outer surface, and  
20 the highest compression at the inner surface. The circumferential stress plot shows a high stress in the inner and outer layers, but a lower stress in the interior. This stress distribution would translate into a variation in stress or strain along the length of a wound material such as a buffer tube.

The circumferential strain, which is a function of both the circumferential and radial stresses, can be interpreted as the circumferential strain in each layer of wound material. In order to understand how the EFL would vary along the length of a buffer tube, it is necessary to look at the circumferential strain. The shape of the circumferential strain distribution along the length can be ascertained from the circumferential strain through the thickness of the layers. If the concentric layers represent a wound buffer tube, the strain in each layer can be interpreted as a sampling of the strain along the length. The stress and strain distribution through the thickness of the layers is shown in Figure 19C.

If the EFL in the buffer tube is constant before the tube is taken up on the reel, it can be assumed that the circumferential strain induced by the winding will directly affect the amount of EFL. The relation between strain and percent EFL can be stated as:

$$EFL = EFL_0 - 100 * \epsilon \quad (5.1)$$

where  $\epsilon$  is the circumferential strain, and  $EFL_0$  is the initial percent EFL. The EFL distribution computed for the case of 30.0 N constant tension is shown in Figure 19D. The circumferential strain has been used to approximate the axial strain, and the length has been normalized to one. An initial EFL of 0.6% was assumed for this case. The EFL curve has the distinct parabolic shape that is observed in the experiments.

The concentric layer model was used to run various cases in order to provide a better understanding of the mechanisms influencing the strain distribution. Simulations were performed to determine the effect of material modulus on the strain. Three values of elastic modulus were chosen, 0.1637, 1.637, and 16.37 GPa. The Poisson ratio was kept at 0.1 for each case, and a constant tension of 30.0 N was used. Plots of the radial and circumferential stress and strain are shown in Figure 20. As expected, a higher Young's modulus decreases

the circumferential strain, and flattens out the curve. This indicates that the winding process would have less of an effect on the EFL distribution for a stiffer material. This is consistent with observations of a more uniform EFL distribution in PBT buffer tubes, which have a higher modulus than the polypropylene equivalent.

5 Another parameter influencing the strain distribution is the diameter of the reel core. Simulations were performed with core diameters of 120.0, 240.0, and 480.0 mm. The total number of layers was kept the same for each case, so the total material thickness was 150.0 mm. The material properties and the applied tension were also kept the same for each case. The modulus was taken to be 1.637 GPa, Poisson's ratio was 0.1, and the tension was  
10 constant at 30.0N. Plots of the radial and circumferential stress and strain are shown in Figure 21. The radius on the x-axis was changed to start at the outer surface of the core instead of at the center, in order to directly compare the results. The stress and strain variation is much larger for the smaller core diameter, and the parabolic shape of the circumferential strain curve is much more pronounced. The length of material is greater for  
15 the larger core diameters, but since the thickness of the material is the same for each case, the influence of the bend radius can still be determined. The observation of a greater variation in stress and strain for the smaller core diameter is consistent with experiments conducted on two different sized reels.

Simulations were performed to investigate the effect of the tension level on the stress  
20 and strain distribution. The tension was kept constant in each case, and the values chosen were 10.0, 20.0, 30.0, 40.0, and 50.0 N. The modulus for each case was taken to be 1.637 GPa, and Poisson's ratio was 0.1. Plots of the radial and circumferential stress and strain are shown in Figure 22. As expected, the increase in tension results in higher radial compression